Robust estimation of fetal heart rate from US Doppler signals

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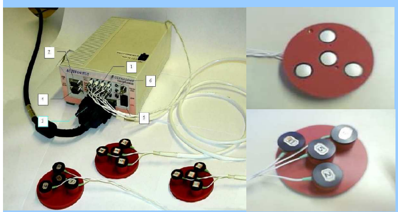
I. Introduction

In utero, Monitoring of fetal wellbeing or suffering is today an open challenge, due to the high number of clinical parameters to be considered. An automatic monitoring of fetal activity, dedicated for quantifying fetal wellbeing, becomes necessary. For this purpose and in a view to supply an alternative for the Manning test, we used an ultrasound multitransducer multi-gate Doppler system. One important issue (and first step in our investigation) is the accurate estimation of fetal heart rate (FHR). An estimation of the FHR is obtained by evaluating the autocorrelation function of the Doppler signals for ills and healthiness fœtus. By modifying the existing method (autocorrelation method), we reduce to 5% the probability of non-detection of the fetal heart rate. These results are really encouraging and they enable us to plan the use of automatic classification techniques in order to discriminate between healthy and in suffering foetus.

II. Equipment



- 3 groups of 4 sensors, each sensor with 5 exploring depths adjustable between 1,88 cm up to 15cm
- Emission Frequency: 2.25 MHz
- Acoustic Driving Power: 1mW/cm²
- Pulse Repetition Frequency: 1kHz

Figure 1: Actifoetus System

III. Objectif

- We want to estimate the fetal heart rate in a long term monitoring. The Doppler signal generated by the fetal moving is disturbed by others Doppler sources (mother's moving, pseudo breathing...).

Part 1: Fetal Heart Rate (FHR) Estimation (sliding window W)

- Algorithm — Auto-correlation $I_1(t,k)=\dfrac{1}{W}\sum_{n=1}^{W-|k|-1} x(t,n)\cdot x(t,n+k)$

1. find the positions $M_0 \ldots M_N$ of maximums of the function I_i ;
2. compute the distances between the positions of two consecutive maximums: $D_n = M_n - M_{n-1}, n=1,\ldots N-1$
3. verify that the differences between the maximum's positions ensure a true physiological rhythm:

$$\Delta_n = |D_n - D_{n-1}| < \varepsilon, n=1,\ldots,N-1$$
$$\mathbf{\Delta}=\{\Delta_1,\ldots\Delta_{N-2}\}$$

- if $\mathbf{\Delta}<\varepsilon$ => the rhythm is: $FHR = mean(\mathbf{\Delta})$
- if not so => no cardiac rhythm detection

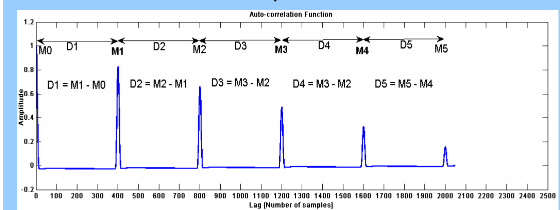


Figure 2: Fetal Heart Rate Estimation

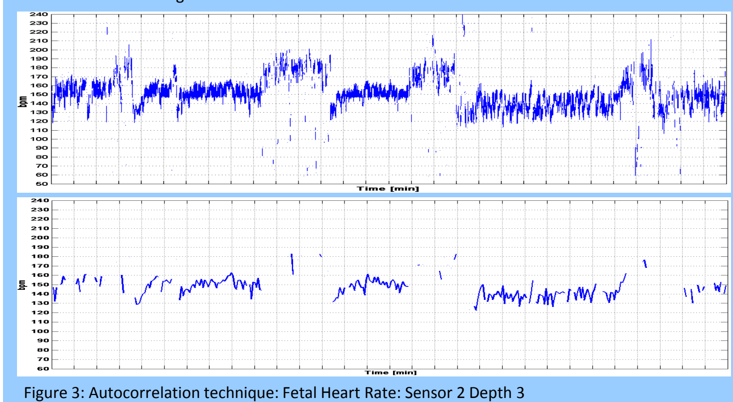


Figure 3: Autocorrelation technique: Fetal Heart Rate: Sensor 2 Depth 3

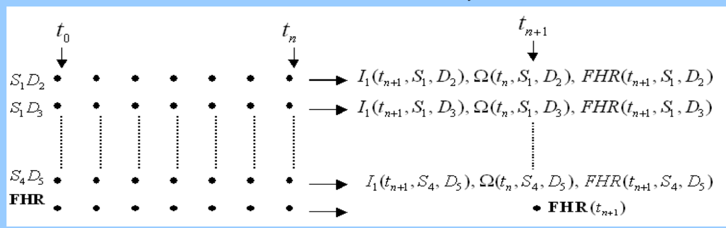
Part 2: Fetal Heart Rate Fusion

- Algorithm 1

1. Identify the number $P(t_{n+1})$ of signals with 1Hz<FHR<4Hz at time t_{n+1}
2. Find the values of auto-correlation function $I_1(t_{n+1},S_i,D_j)$
3. Sort the $I_1(t_{n+1},S_i,D_j)$ in descending order. In case of equals values choose the channel with higher probability $\Omega(t_n,S_i,D_j)$

$$FHR(t_{n+1}) = \arg\max\left(I_1(t_{n+1},S_i,D_j),\Omega(t_n,S_i,D_j)\right)$$

4. Update the detection probability $\Omega(t_{n+1},S_i,D_j)$



- Algorithm2

1. Find the signals:

$$FHR(t_{n+1},S_i,D_j) < \left|\mu_{FHR}(t_n) - 3\sigma^2_{FHR}(t_n)\right|$$
$$FHR(t_{n+1},S_i,D_j) < \left|\mu(t_n,S_i,D_j) - 3\sigma^2(t_n,S_i,D_j)\right|$$

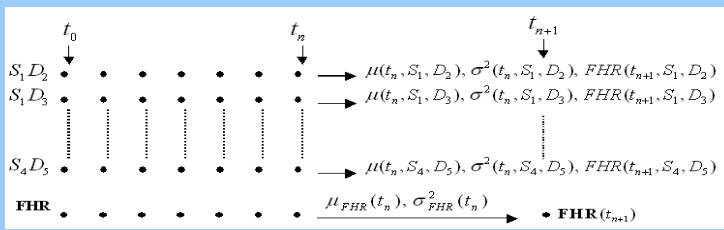
2. Find the weights $k(t_{n+1},S_i,D_j)$

$$\sum_{p=1}^{P(t_{n+1})} k_p(t_{n+1},S_i D_j)=1;$$

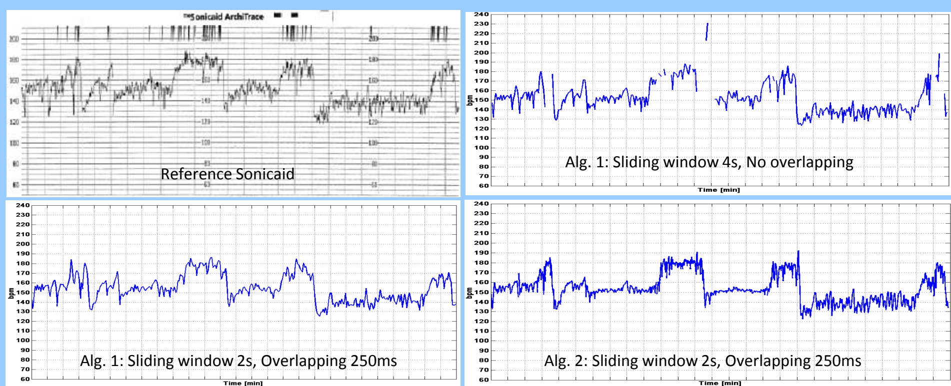
$$k_p(t_{n+1},S_i,D_j)=\frac{1}{\sigma_p^2(t_n,S_i,D_j)\cdot\sum_{p=1}^{P(t_{n+1})}\left(\frac{1}{\sigma_p^2(t_n,S_i,D_j)}\right)}$$

3. Find the new heart rate

$$FHR(t_{n+1})=\sum_{p=1}^{P(t_{n+1})} k_p(t_{n+1},S_i,D_j)\cdot FHR(t_{n+1},S_i,D_j)$$



IV. Experimental Results



IV. Conclusions

- auto-correlation is the method which gives the best trade-off in terms of probability detection and number of operation
- the size of the analysing window and the overlapping step are very important
- the second fusion algorithm seems give a better estimation of the fetal heart rate comparing with the first fusion algorithm

V. Perspectives

- estimate FHR using the other groups of sensors
- estimate the FHR applying the algorithms over sets of grouped signals (i.e. same depth)